Cartography and terrain mapping using IRS-1C data

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IRS-1C satellite provides multispectral LISS-III and high resolution steerable panchromatic data for cartographic applications. The updation of topographic maps will be one of major applications of these data. This article gives a theoretical assessment of the cartographic potential of IRS-1C imagery and the early results from few stereo pairs. For moderately undulating terrain, stereo pairs with B/H of 0.5 and moderate radiometric contrast, the elevation information derived from IRS-1C imagery is sufficient for 1 : 25,000 scale mapping. Standard linear features in topographic maps of 1 : 50,000 and 1 : 25,000 scale maps could be reidentified and registered on the imagery. Identification of new features is possible for mapping at 1 : 25,000 and 1 : 50,000 scale.

INDIAN Remote Sensing Satellite IRS-1C carries onboard push-broom linear CCD scanner cameras for providing high resolution imagery of Earth's surface. Updation of topographic maps will be one of the major remote sensing applications. The issue of usefulness of IRS-1C data for topographic mapping purposes is discussed in this article from two angles, viz.

1. A theoretical assessment of cartographic potential of IRS-1C imagery and
2. Early results with available IRS-1C imagery.

Based on both theoretical possibilities and firstcut assessment, conclusions related to cartographic potential of IRS-1C are drawn.

IRS-1C specifications related to terrain mapping

IRS-1C carries three cameras, viz. a multispectral LISS-III camera, a high resolution steerable panchromatic camera and a wide field sensor. Of these, the first two have resolution capacity for cartographic applications. Basic characteristics of these two sensors are given in Table 1.

The panchromatic camera can be steered up to ±26°. Thus by acquiring imagery over the same ground area from multiple orbits a stereoscopic coverage can be obtained and by applying appropriate models, a terrain height profile can be determined. The IRS-1C mission can thus provide both planimetric and elevation information.

The following *data products* planned for IRS-1C mission can be used *for cartographic applications*:

1. Radiometrically corrected raw geometry basic stereo pair of PAN data. This product is useful for stereoscopic viewing and terrain elevation determination.
2. Geocoded data products, produced by mosaicing a number of data sets, if necessary, to give a toposheet compatible product in terms of format, resolution and layout. For IRS-1C, these products are provided in 1 : 50,000 scale for LISS-III and additionally 1 : 25,000 scale for PAN.
3. Merged products prepared by artificially merging the contents of registered high resolution PAN and low resolution multispectral LISS-III data to produce high resolution multispectral data. These products are expected to allow better visual interpretation capability for linear features of interest in cartographic applications.

Issues in terrain mapping using spaceborne stereo imagery[1]

The information content of a topographical map compiled by photogrammetric methods is provided by the ground resolution of the images expressed in m/line pair for camera systems and m/pixel for electro optical systems. The average resolution of an aerial photographic imaging system which is a combined influence of lens, film and the forward motion can be taken as ranging from 40 lp/mm for systems not using forward motion compensation to 140 lp/mm for modern system using forward motion compensation (FMC). The resolution in m/lp is given by:

$$R_{m/lp} = \frac{\text{Photo scale}/1000}{R_{lp/mm}}.$$

Table 1. Basic characteristics of PAN and LISS-III sensors

Parameter	PAN	LISS-III VNIR	LISS-III SWIR
Spatial resolution (m)	5.8	23.6	70.8
Swath (km)	70	142	148
Spectral bands (μm)	0.5–0.75	0.52–0.59 0.62–0.68 0.77–0.86	1.55–1.70
No. of gray levels	64	128	128

The values of $R_{m/lp}$ for aerial photographs at 1 : 50,000 scale photography are 1.25 and 0.357 for systems without FMC and with FMC respectively.

Taking 1.25 m/lp as the resolution of aerial photograph and if the content of the image are to be as much as that of a 1 : 50,000 aerial photograph then the pixel size of the satellite image should be 0.5 m, as given by $R_{m/lp} = 2^{3/2} * R_{m/pixel}$, where $2^{3/2}$ is the Kell's factor.

Even though the information content or features that can be extracted from any given imagery is determined by photographic resolution and scale or more directly by the resolved distance on the ground, it is difficult to establish a linear relationship between map scale and resolution required as some features like roads, rail, canals, etc. have to be depicted on a map irrespective of the scale. The smallest feature that can be depicted on a map is assumed to have a least dimension of 0.25 mm. In order that an object be identifiable on the imagery in medium contrast conditions, it must be imaged by at least 5 resolution elements. It follows then that resolution required for imagery can be estimated as

$$\text{Ground resolution} = 0.2 \times 0.25\ \text{mm} \times \text{map scale number}$$
$$= 5 \times 10^{-5} \times \text{map scale number}.$$

For 1 : 50,000 scale map product the required ground resolution = 2.5 m.

However for detection of features in good radiometric contrast condition, it is sufficient to image the object in 2–3 resolution elements. In such cases a pixel resolution of 5–6 m is sufficient. Thus IRS-1C resolution is sufficient for identification of features required for 1 : 50,000 scale mapping.

Pixel size from photogrammetric criteria

The measurement of reliable terrain height from digital stereo data recorded by tilting camera is heavily influenced by geometric principles involving B/H ratio, sensor attitude, pixel size and correlation accuracy. The photogrammetric approach assumes sufficient transformation capability for bringing corresponding images in approximate congruence. The error p_x expected in image parallax removal when employing digital correlation technique is given by

$$p_x < K * (\text{pixel size}),$$

where values $0.2 < K < 1.5$ show the degree of correlation.

The parallax error may be converted into the height error (h) through the use of base to height ratio inherent in the parallax equation, when the Y-parallax is 0.

$$h = \frac{H}{f} \cdot \frac{H}{B} \cdot \sigma p_x$$

and analogous to digital sensor

$$\Delta H = \frac{\Delta P \cdot SF}{2 \tan \alpha},$$

where σp_x or Δp is the total error in parallax measurement in the image plane, SF, the scale factor $= H/f$; f, the focal length; H, the flying height of sensor above the average terrain elevation; B, the base distance between exposure stations; α, the half angle between intersecting rays, referenced to local vertical ($H/B = 1/2 * \tan\alpha$).

Scale factor (H/F) multiplied by parallax (σp_x) in the image plane yields the pixel size on the ground:

$$H/F * \sigma p_x = \sigma P_x = K * [\text{pixel size (m on ground)}].$$

Therefore, pixel size $= 1/K * B/H * \sigma h$.

The relationship between the closest relative contour interval meeting the 90 per cent criteria and the precision of instruments (s) for relative spot heights is given by

$$\text{C.I.} = 3.3\ s\ h$$

or

$$sh = 0.3 * C.I.$$

Pixel size $Ps = 1/K * B/H * 0.3 * C.I.$

Assuming $B/H = 0.6$ and the desired contour interval for 1 : 50,000 mapping is 20 m we get

$$Ps = 0.83 \times 0.6 \times 20\ \text{m}$$
$$= 10\ \text{m for } 1 : 50{,}000 \text{ scale maps.}$$

The accuracy of spot heights referenced to a recognized datum is largely determined by factors which create geometric displacements in the sensor data and produce correlation or measurement errors in the along track direction. These displacements or errors (DX) may be expressed in fractions of pixel at the ground or in arcseconds.

From a comparison of the mapping standards and the standards of IRS-1C data products it can be concluded that:

- It is possible to obtain point height and contour information compatible with 1 : 50,000 and 1 : 25,000 scale topomaps from IRS-1C PAN stereo pairs.
- Most of the spatial land cover information required for updation of topographic maps at 1 : 50,000 scale can be obtained from IRS-1C PAN and LISS-III data. Certain features may require field verification. At 1 : 25,000 scale a larger component of field verification and complementation may be required.

Description of a software system for terrain mapping using IRS-1C imagery[2]

The software system developed at Space Applications

Centre (ISRO) for terrain mapping using IRS-1C imagery was used for analysis of IRS-1C capabilities. This system has the following basic elements: (i) Ground Control Point (GCP) tools, (ii) Digital Elevation Model (DEM) generation and editing, (iii) Orthoimage generation, (iv) Quality evaluation, and (v) Mapping using GIS.

All these are additionally supported by image processing and graphics libraries. The hardware consists of an Indigo-2 R-4000 based softcopy photogrammetry workstation with stereo display monitor, crystal eye glasses for stereo view, a scanner and a plotter. The details of the software system are explained in the subsequent sections.

GCP generation

This consists of a scanner system, wherein the desired maps are scanned in an appropriate resolution. The resolution in dpi (dots per inch) depends on its scale. The digital image is properly thresholded, so that all the linear features are clearly identifiable. The scanned image is then transferred to the main system for GCP identification along with the stereo pair images.

Points which are clearly identifiable both in image and scanned map are selected as GCPs. Permanent features like road crossings, canal junctions with roads, etc. are better features than the dynamic features like river bends, etc. The points are digitized using the graticules available in the scanned map. Coordinates of a point, in terms of latitude and longitude, are obtained by a projective transformation on the surrounding known grid points of the map. The height of the point is interpolated from the nearest elevation contour lines. The image coordinates of the control points are identified parallelly on the display device.

DEM generation and editing

A DEM is a numerical description of the surface of an object on measured or derived coordinates of numerous scattered points. With the advent of digital photogrammetry workstations with high computation power, DEMs can be derived by purely digital approach, from the satellite stereo pairs. The digital mode of DEM generation from a satellite stereo pair consists of the following steps:

Automatic conjugate point identification. One of the research areas of current interest in photogrammetry is related to methods for automatic measurements of parallaxes and coordinates in stereo images.

In this system we implemented a hierarchical automatic point matching technique based on an interest operator[4,5] followed by an area-based correlation. Hierarchical approach is selected to make the search area sizes (for correlation) very small at each pyramid of the hierarchy, to gain the computational advantage. Interest operator selects the candidate points for matching. The first pyramid starts on the reduced resolution image, by a factor of 4. There are three pyramids in the hierarchy. At each pyramid, interest points are found out in one of the images (called reference). Approximate coordinates for these points are found out by a local mapping on the previous level's (pyramid) conjugate points. The procedure continues till it reaches the last level, i.e. full resolution. The number of points matched in the last level are the final conjugate points. A number of inbuilt checks on the reliability of matched points are implemented. The first check is a two-way correlation, in which the match point should get the similar correlation coefficient (above a particular threshold) in forward as well as in reverse direction. Secondly, it should satisfy the maximum and minimum height criteria of that area.

Determination of orientation parameters. The raw IRS-1C scene suffers from a number of geometric distortions. These are due to the factors such as satellite orbit and attitude variations, sensor geometry, tilt angle, terrain relief, etc. To correct distortions/orient the image, a method of modelling the orbit and attitude parameters[6,7] of IRS-1C has been developed using GCPs. The elliptic Keplarian orbit can be described by six independent parameters, viz. semi major axis (a), eccentricity (e), inclination (i), longitude of ascending node (W), argument of perigee (w), and true anomaly (F). Space resection refines these six parameters using modified collinearity condition equations, which states the perspective centre, image point and the corresponding ground point lie in a straight line at the time of imaging: $(x, y, -f)^T = s.M.(X_A - X_s)$, where $(x, y, -f)$ are the image coordinates of the GCP, s is the scale factor, X_A are geocentric coordinates of the GCP and X_s are the perspective centre coordinates. M is transformation matrix, which is a function of tilt angle, attitude and orbit. The major components of the dynamic motion are the earth's rotation and the satellite movement along the orbit path. These motions have been modelled as linear angular changes of F and W with time as $F = F_0 + F_1 \cdot t$ and $W = W_0 + W_1 \cdot t$. Assuming the effects of e and w are negligible, the parameters to be updated in the resection are F_0, F_1, W_0, W_1, a and i.

Determination of 3D ground coordinates by the method of space intersection. The 3D coordinate of a point of interest can be computed in the object space using inverse collinearity equations[6]. Intersection of the rays coming from conjugate points determines the object coordinate. However due to some error the rays do not meet in a single plane. So the midpoint of the vector of perpendicular distance between the two rays is taken as the object point. The points thus obtained will be approximation of the actual value. The collinearity equations are linearized with respect to ground coordinates of the points, and are solved using the least square method to get the corrections in an iterative manner.

Bundle adjustment. For further refinement of both satellite orientation and the derived DEM, a bundle adjustment software developed jointly by SAC and German Aerospace Research Establishment (DLR), Germany, is used. In this DEM is computed in a combined solution for GCP coordinates, conjugate point coordinates and orientation parameters of the stereo pair imageries. The output of space intersection, i.e. the irregular DEM, is used as initial approximation of the iterative weighted least squares solutions of the bundle adjustment. Depending on the residuals at each point after the least square solution, spurious points can be identified and eliminated. The procedure is well tested for SPOT and is getting implemented for IRS-1C.

Height interpolation. Space intersection technique generates an irregular grid of DEM. To compute heights of regularly spaced grid points of specific interval, one has to interpolate heights among the arbitrarily distributed points. In the current system four options are available for height interpolation, viz. weighted average, polynomial fit, finite element method and Kriging. Out of which most popularly used one is weighted average method, because it is simple and less time consuming. In this the weights for a given point are calculated depending on the Euclidian distances of its four neighbourhood points.

Point editing. Currently bad points of DEM are detected by a slope thresholding done automatically during the interpolation. Eliminating these points from the irregular set of points and reinterpolating once again, produces improved result. The slope threshold depends on the overall undulation of the area. It is observed sometimes, though spurious points are eliminated by this method, that wherever steep slopes are there, some good points are also getting eliminated. Efforts are going on to develop an interactive editing package, wherein user detects the bad points on the stereo display with a wire mesh overlay of the already available conjugate points. User can eliminate/correct those points and reinterpolate to get the corrected DEM.

Orthoimage generation. Basically a precise ground to image relation along with the DEM and the raw data are the requirements to generate an orthoimage. This is a geocoded product corrected for all the geometric errors, including terrain relief and the camera tilt, which can be directly used for topographic mapping. The orthoimage can directly go into a GIS. For an output grid of latitude and longitude and height (obtained from DEM) time and pixel of the input image can be calculated by an iterative way with the help of equations (2) and (3) using the updated orientation of the image. And the gray value for this point is generated by resampling the input image. The DEM can be the one derived from the same stereo pair or it is digitized/derived from map. In case of map DEM GCPs are also required additionally, to get mapping between ground and image.

Quality evaluation. One of the most critical components of the mapping is the accuracy of the product used in terms of its tickmarks and the internal distortion. The system contains accuracy checks at every process level, i.e. the model accuracy on GCPs and on check points, is given immediately after space resection and intersection. In addition to this, the orthoimage evaluation with respect to its tickmarks[2] is done on checkpoints within the system. The checkpoints are identified on the orthoimage manually, and their estimated positions with respect to the tickmarks are compared with the actual values. The RMS of these errors are quoted as the location accuracy and the standard deviation represents the internal distortion. Apart from this quantitative approach, orthoimage can be evaluated qualitatively by overlaying map features either digitally or photographically. The DEM can be qualitatively evaluated by (i) draping the orthoimage on the derived DEM and comparing this with the draping of orthoimage over map-derived DEM and (ii) comparing the contours obtained from both image-derived DEM and map-derived DEM.

Mapping using GIS. For better visual interpretation of linear features in conjunction with their background texture, merging of PAN data with that of LISS-III is helpful/required. Merging can be done after generating separate orthoimages of the same area of interest from both PAN and LISS-III data.

Terrain mapping needs derivation of cultural features, elevation changes and thematic information from the derived DEM and orthoimage. This task can be better achieved by using a GIS. Basic tools required for terrain mapping are slopes, surface area, volume, line of sight coverage, draping, perspective view, etc., and these can be efficiently derived/obtained in the GIS environment.

Early results from IRS-1C data evaluation for cartographic purposes

The first cloud-free stereo pairs from IRS-1C panchromatic data available over Maharashtra region are taken for generating DEM and orthoimage. The data specifications are given in Table 2. The stereo pair was generated at National Remote Sensing Agency (NRSA), Hyderabad, using an operational software developed by SAC. The data have undergone only radiometric corrections and no geometric corrections are applied. Two mapsheet areas (47M/13/SE and 56A/1/NW) are considered, which are having undulations between 80 and 160 m. Since the overlap between stereo images is only 60%, full map sheet area is not available for any of the above two map sheets. Hence an area of 7.5" × 7.5" is selected nearer to the above map sheets (80% of total map sheet area is covered), through corner coordinates. Ten ground control points are selected from each stereo pair, and they are digitized from available 1 : 25,000 and 1 : 50,000 scale mapsheets. Out of these four/five are used as control points and remaining five/six are used as check points. Table 3 gives the RMS values of accuracies obtained from the model on check points. This shows the model accuracy depends on the input GCP accuracies. GCPs collected from 1 : 25,000 scale map resulted in a better DEM accuracy than the GCPs collected from 1 : 50,000 scale, as expected.

DEM and orthoimages are generated for both the map sheet areas using the software system described in the previous section and detailed evaluation is carried out for set 1. The results are given in Table 4. This error is a result of all the errors namely, DEM error including GCP error, interpolation error and model error.

Table 2. Stereo pairs used for testing

Set	Path/row	Subscene	Date of pass	Tilt angle
1	097/058	D7	15-01-1996	–14.5°
	097/058	C8	19-01-1996	12.8°
2	097/058	D4	15-01-1996	–14.5°
	097/058	C5	19-01-1996	12.8°

Table 3. Model accuracy (RMS in m) on GCPs and checkpoints

	GCPs			Checkpoints		
Set	Easting	Northing	Height	Easting	Northing	Height
1*	1.2	3.0	8.5	10.5	27.5	13.6
2**	3.0	4.5	6.7	18.3	36.3	28.9

*Points are collected from 1 : 25,000 scale mapsheets; No. of GCPs: 5; No. of checkpoints: 5.
**Points are collected from 1 : 50,000 scale mapsheets; No. of GCPs: 4; No. of checkpoints: 6.

Table 4. Evaluation results of orthoimage

Map sheet	Error in easting (m)	Error in northing (m)
47M/13/SE	15	20
56A/1/NW	22	36

Number of points available for evaluation are 5 for each set.

A qualitative evaluation of orthoimage for set 1 is done by

(a) overlaying all linear features of map, with the help of a tracing at 1 : 25000 scale, which almost sits onto the orthoimage with the above accuracy. Further, orthoimage shows the recent information like new roads/constructions and other elevation changes like quarrying, etc., which can be used for updation.
(b) Comparing the drapings of (i) the orthoimage over derived DEM from the stereo pair and (ii) orthoimage over map-derived DEM. Draping from map-derived DEM showed blocky effect/discontinuities, because of lack of continuous information of elevation, whereas the other draping showed smooth variation of the terrain, since it has the continuous information of terrain elevations. The map DEM is generated by digitizing the 10 m contours from the 25000 scale map.
(c) Comparison of elevation contours showed a good match of peaks and valleys of elevation, from both DEMs derived from image and map.

Conclusions and recommendations

The early results described above can be categorized in three classes:

1. The reconstruction of terrain profile. This is related to the precision of height determination for various terrain conditions, viz. highly undulating, moderately undulating and flat. It is shown that in case of moderately undulating terrain conditions with moderate contrast the terrain model can be automatically reconstructed to meet requirements of 1 : 25,000 scale mapping. The experiments described above were conducted with stereo pair acquired with approx. 0.5 base to height ratio. Thus, for regions having moderate radiometric contrast the elevation information derived from IRS-1C imagery is sufficient for 1 : 25,000 scale mapping. For other types of terrain this conclusion comes from the capability of achieving any base to height ratio up to 1.1.

It has been seen that the breaklines and breakpoints can be identified with high confidence in manual mode. However, its identification in automatic mode is a subject of further research.

2. Availability of standard map features in imagery. It is concluded that the linear features available in the 1 : 50,000 and 1 : 25,000 scale topographic maps could be reidentified and registered on the corresponding imagery. This was achieved in part due to good orthoimage quality.

3. Identification of new features for mapping at 1 : 50,000 and 1 : 25,000 scale. A large number of linear features having similar texture and contrast as classified features from map were available in the PAN imagery. These could be easily transferred to the base map. A

positive identification of these features into various classes could not be carried out due to mixed spectral response. This situation can be rectified by registering panchromatic high resolution imagery with medium resolution multispectral imagery. This as well as field verification of alignments and identification is planned to be carried out in near future.

Day to day capability for cartographic applications may be different from the theoretical assessment due to factors like atmospheric conditions, mosaicing-related problems, etc. To get realistic capabilities of IRS-1C for cartographic applications it is planned to conduct map updation exercise over a test site undergoing fast development. This will be followed by field verification and assessment of percentage of various map features at 1 : 50,000 and 1 : 25,000 scale available from a given set of imagery.

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